AD-A161 955 A RAMAN FEL (FREE ELECTRON LASER) AT 2MM WAVELENGTH 1/1
DESIGN OF AN EFFICIENCY-ENHANCED RAMAN FEL OSCILLATOR
(U) DARTMOUTH COLL HANOVER NH J MASUD ET AL OCT 85

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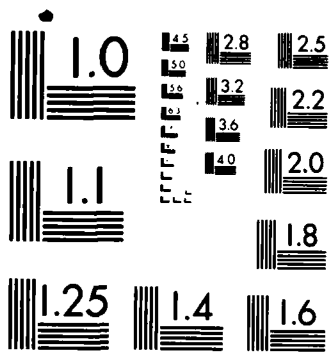
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ANNUAL TECHNICAL SUMMARY AND STATUS REPORT

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I. INTRODUCTION

In the last year, we have been able to overcome several serious technical problems in the Raman FEL experiment. Initial gain measurements showed that the overall gain--inclusive of coupling loss-- was only a few db at 1.2mm (wiggler period 1.1cm), too small to permit accurate measurements in our single shot experiment. This was confirmed by a 3D numerical calculation of the dispersion (the 1D version was too optimistic). Therefore, we redesigned the wiggler for period 1.45cm with B up to 1kG and B = 8.8kG, so that quiver velocity up to .15c could be obtained to develop high gain. The choice of wiggler period was consistent with a convenient operating range of accelerator energy (600- 800kV) and a molecular laser at 2.14mm (CO_2 pumped molecular NH_3). A simple oscillator configuration provided a high power signal so that a parameter study of wavelength, beam energy, and pump field could generate data which could be compared with theory. Having obtained about 2MW from the simple (constant period) FEL oscillator--which incidentally is in agreement with the theoretical predicted saturated efficiency of this system (~3%), we then configured the amplifier and we are presently making gain measurements. This information is contained in part IIA, in a paper delivered at the FEL meeting on September 12, 1985. We anticipate that the amplifier measurements will be completed this year: this will complete the dissertation

research of Jamil Masud.

Also, a 1D tapered wiggler oscillator calculation was done by FG Yee, and was accepted for publication in the December 1985 (High Power RF) issue of the IEEE Plasma Science journal: this is included in section IIB . The theory used a solution for the generalized pendulum equation, with self- consistent field and space charge effects (Raman) included. The feedback was not calculated exactly; rather, the results of small-signal and saturated operation were pieced together to design a system with adequate gain and high power output. [It is worthwhile to note here that an exact oscillator calculation is being done by P. Sprangle's group at NRL, and that we hope to collaborate in the sense of providing data for their code; the actual computing time is very lengthy, however]. This high efficiency oscillator is the experimental program which we are proposing for 1986. It will build on the results of our Thomson-scattering work (which measured low parallel momentum spread), the amplifier, and the simple oscillator, mentioned above.

II. TECHNICAL SUMMARY

A: A Raman FEL at 2mm Wavelength

(J .Masud, F.G. Yee, T.C. Marshall, S.P. Schlesinger)

The nonlinear physics of the free electron laser (FEL) involves waves set up in a nearly cold electron beam when it passes through the undulator. In addition to the pump field and the growing scattered EM wave moving parallel to the electrons, there is a disturbance in the beam space charge caused by the ponderomotive force. Since a dense electron beam ($\omega_p L/\gamma c >> 1$) also may support a space charge (or plasma) electrostatic wave, there can be an important interaction when the ponderomotive force resonates with this mode. Even when the pump is weak, exponential gain can occur, and this is referred to as the "Raman" FEL. The name is drawn from Raman lasers, where an intermediate energy level is involved in a stimulated scattering interaction with an optical pumping source.

In this paper we discuss initial experimentation using a simple Raman oscillator and amplifier. The purpose of the oscillator is to define initially the regions of substantial gain by observing the emission wavelength. Following this, the gain is observed in an amplifier configuration, using a CO_2 laser pumping an NH_3 gaseous laser at 140GHz (2.14mm).

EXPERIMENTATION

We use a 60cm long bifilar helical undulator, having tapered entry and exit (period: λ_c=1.45cm), positioned over a 5mm dia, ~100A beam enclosed in a 6.2mm dia drift tube (TE11 cutoff, 27GHz). In a previous experiment, a Thomson backscattering diagnostic showed[1] that the intrinsic parallel momentum spread was < 1/2%, and was largely dominated by the beam space charge. In this new configuration, the only important change is to reduce the diameter of the drift tube, which should improve the beam quality. In the energy range of the beam (650-750kV), for guiding field, B_o, of 8.8kG, the electron orbits are stable type I, viz, $\gamma k_o v_{\parallel} > = eB_o/mc$, where $k_o = 2\pi/\lambda_o$. The guiding field causes an enhancement in the electron quiver velocity induced by the undulator, so that $v_{\perp}/c$ ~ 10% for $B \gtrsim 500G$. The forward scatter mode is convective, and therefore will not compete with the desired backscatter (FEL) mode. The configuration of the accelerator, the FEL amplifier, and its assortment of gas lasers is shown in Fig 1.

In the oscillator, the upstream reflector is just a thin annular ring concentric with the electron beam. The thickness of the ring is ~ 1.5mm, which reflects only ~ 50% of the incident radiation (it is thin to avoid a substantial electrostatic perturbation on the beam). The downstream reflector is the quartz vacuum window, with ~ 20% reflectivity. Thus the oscillator will operate only if the single pass FEL gain is very high. A pulse of radiation at ~ 2mm is shown in

Fig 2. The power at the output window was observed to be 1Mw (determined by a calibrated receiver). As a comparable amount of radiation is emitted into the diode, we compute an efficiency ~ 3%, which compares favorably with theory ($\omega_p/\gamma k_c c$). The long start time is required because of the large cavity losses. We do not know why the FEL pulse does not last longer, but it may have something to do with the high intensity radiation which is beamed into the diode. Also shown in Fig 2 is the dependence of power radiated upon undulator pump field. The threshold for oscillation is high because the losses at each end of the cavity are very high. In the upper range of $B_\perp$, we leave the Raman region and enter the region of the "strong pump" instability. The power was measured using the radar formula and a set of attenuators which we calibrated in the FEL's own radiation, so that the crystal detector remained in its linear response zone.

Next, spectroscopy was done on the radiation emitted from the simple oscillator, using a millimeter grating spectrometer. The latter was calibrated against conventional 2 and 3mm sources. The resolving power of the instrument was ~ 100, and in Fig 3 we see a profile of the oscillator emission line. The total linewidth, 1.7%, compares favorably with the linewidth measurement of the first Raman FEL [2]. The intrinsic linewidth of the radiation is only about one percent, and is therefore less than the undulator linewidth (~2%). One would expect that for an oscillator the homogeneous linewidth should be smaller than 1/N by roughly a factor of the square root of

the number of radiation bounces, which should account for the factor of two. On the other hand, the inhomogeneous line broadening is also ~ 1% [1].

In Fig 4 we show a plot of the dependence of scattered wavelength upon beam energy, in which a comparison with Freund's three-dimensional theory is indicated [3]. The agreement with the theory is good, especially at lower pump field, farther from magnetoresonance; only the point at longer wavelength falls substantially away from the prediction (the electron energy is based on the empirical determination of the diode voltage). At lower energy, smaller transmitted current may result from high $V_\perp$, and this may explain the discrepancy. These results show that the amplifier should be operated at a diode voltage of ~ 750kV.

The amplifier experiment requires a dependable high power (~ 1kW) source of coherent signal in the millimeter region. Initial efforts utilized a 1.2mm line emitted from isotopic methyl fluoride, pumped by a CO_2 TEA laser. However, the 3D theory predicted low gain, and it was not possible to obtain reliable quantitative data using this line, given the experimental limitations on guiding field and accelerator energy, because of the necessity for a short undulator period (1.1cm). Recently a new long wavelength (2.14mm) ammonia laser - also CO_2 TEA pumped - has been studied [4], and this should be a more satisfactory source of signal input for the FEL. The longer wavelength permits an increase of undulator period (1.45cm, the same as for the oscillator described above). Gain

measurements are in progress. In Fig.5 is shown a theoretical 3D computation for the FEL gain of our apparatus in the vicinity of the NH_3 line: ~ 30db single-pass power gain should result.

ACKNOWLEDGMENT: This research was supported by the ONR, grant N0014-79C-0769.

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FIGURES

Fig. 1: Layout of the experimental hardware, consisting of accelerator, FEL, gas lasers, and diagnostics. The timing of the lasers and the accelerator pulse is crucial, < 50nsec jitter permissable.

Fig. 2: Dependence of FEL oscillator power on pump field amplitude. Total power output, ~ 2MW. Inset: diode voltage pulse (above) and radiation pulse (below) at 2mm wavelength; time scale, 50nsec/div.

Fig. 3: FEL oscillator line profile, obtained from a grating spectrometer.

Fig. 4: FEL wavelength for different energies. The theory curve is for the following parameters: beam current 200A, TE11 mode in drift tube, guiding field 9kG, undulator period 1.45cm, B = 800G.

Fig. 5: Theoretical calculation for the spatial growth rate, after [3]; same conditions as Fig 4 except beam current = 100A: A = 740kV; B = 720kV; C = 700kV. The dashed line indicates the 140GHz ammonia laser.

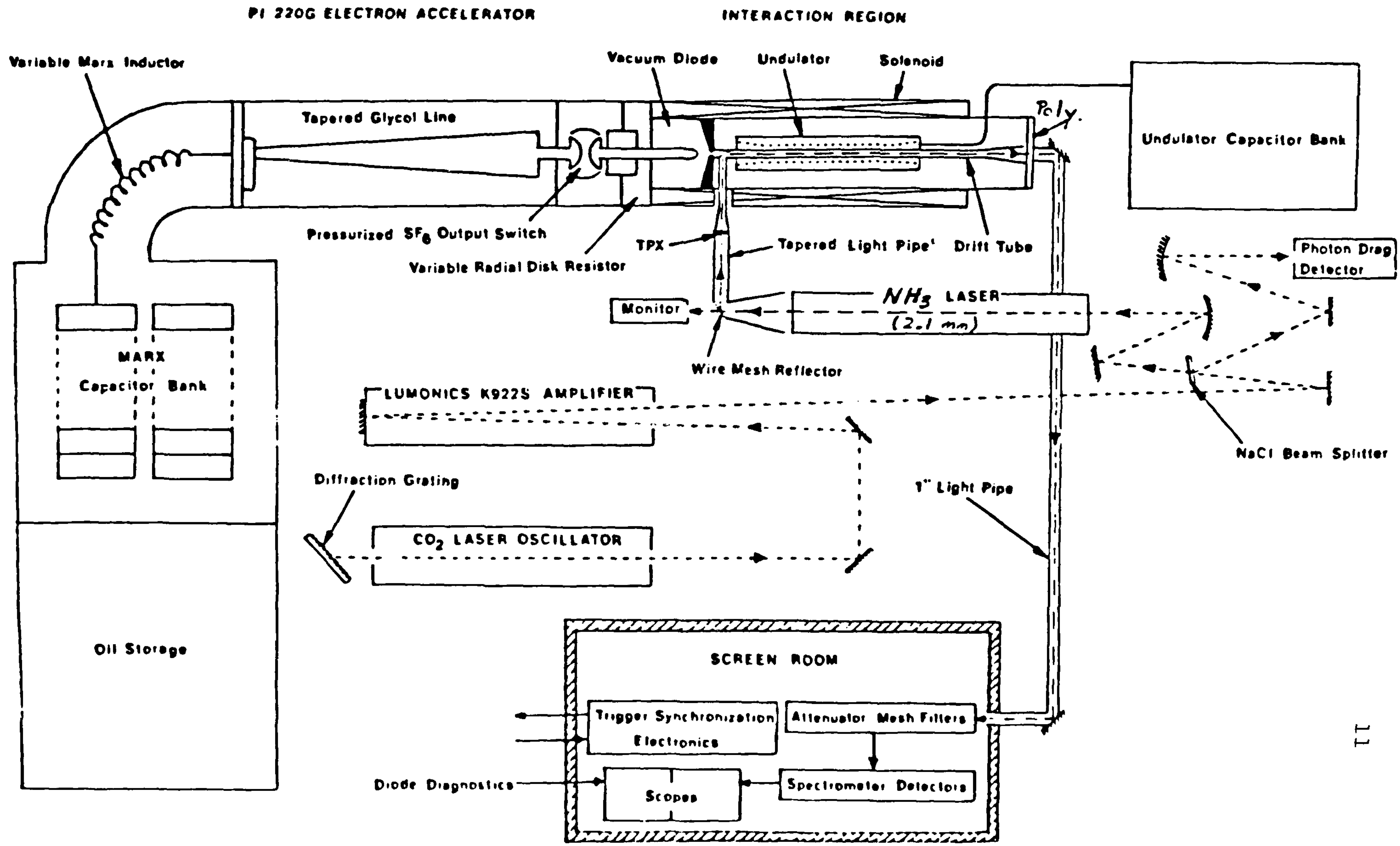
PI 220G ELECTRON ACCELERATOR
INTERACTION REGION
Variable Marx Inductor
Vacuum Diode
Undulator
Solenoid
Poly.
Undulator Capacitor Bank
Tapered Glycol Line
Pressurized SF_6 Output Switch
Variable Radial Disk Resistor
TPX
Tapered Light Pipe'
Drift Tube
Photon Drag Detector
NH_3 LASER (2.1 mm)
Monitor
Wire Mesh Reflector
MARX Capacitor Bank
LUMONICS K922S AMPLIFIER
NaCl Beam Splitter
Diffraction Grating
1" Light Pipe
CO_2 LASER OSCILLATOR
Oil Storage
SCREEN ROOM
Trigger Synchronization Electronics
Attenuator Mesh Filters
Diode Diagnostics
Scopes
Spectrometer Detectors

FIGURE 1

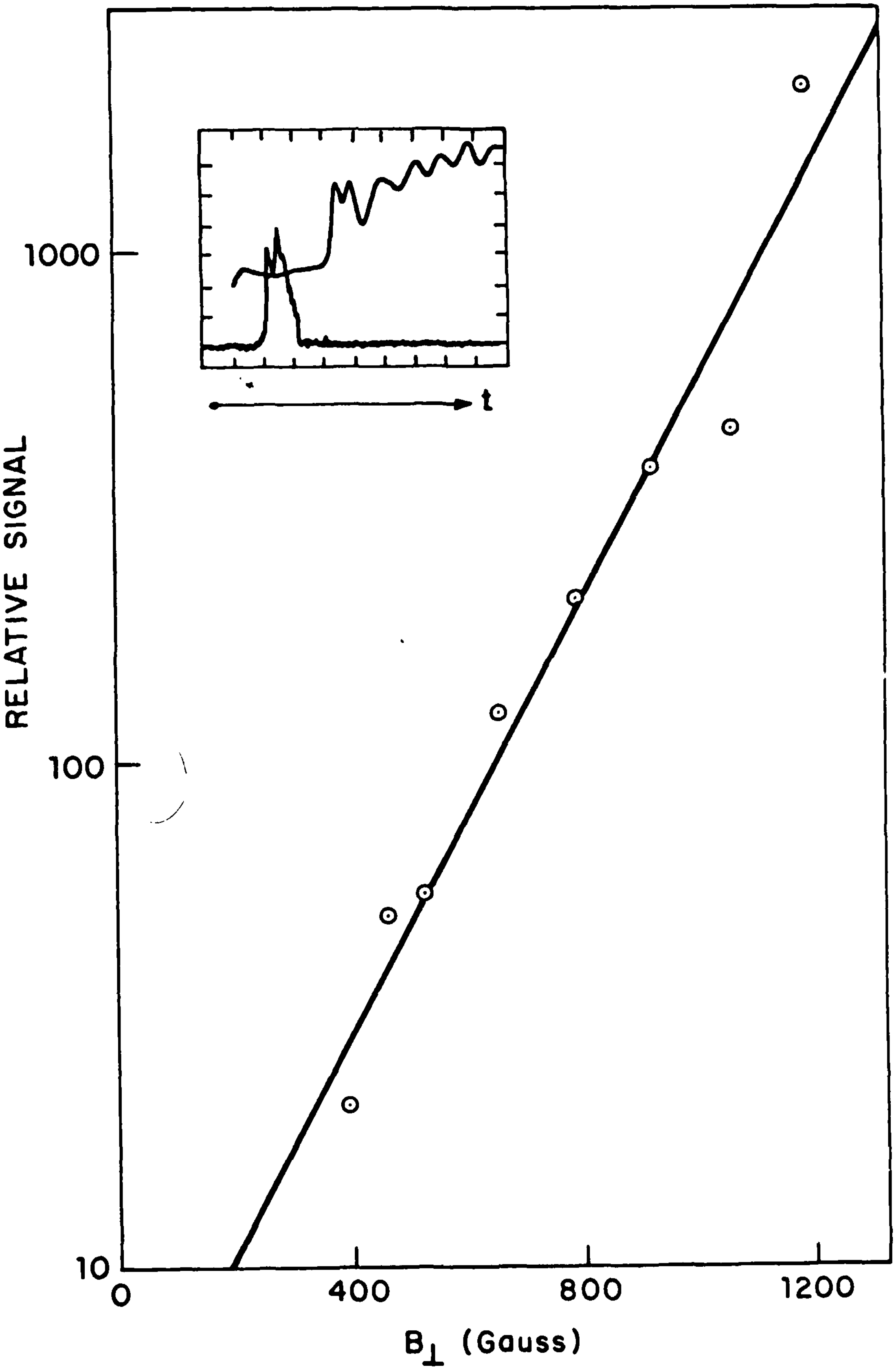

FIGURE 2

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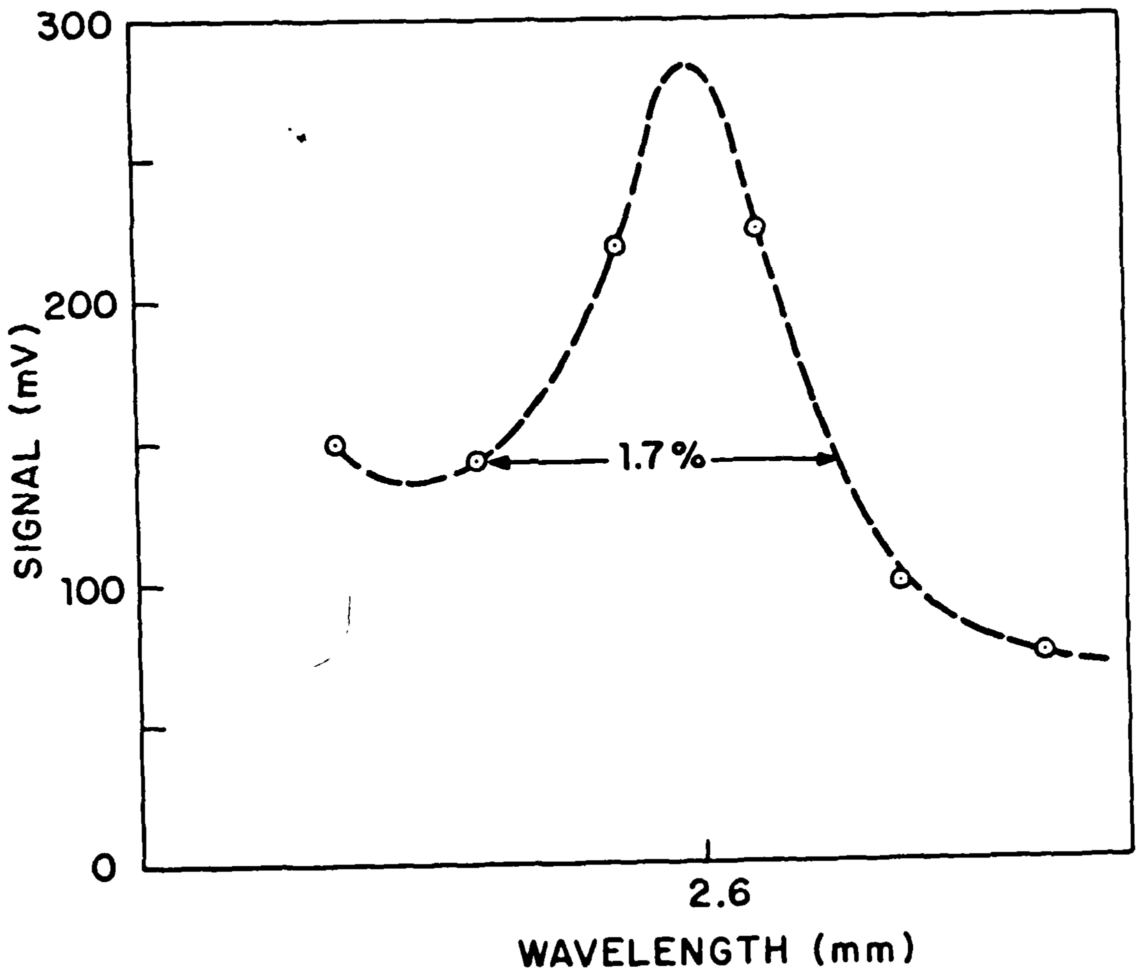


FIGURE 3

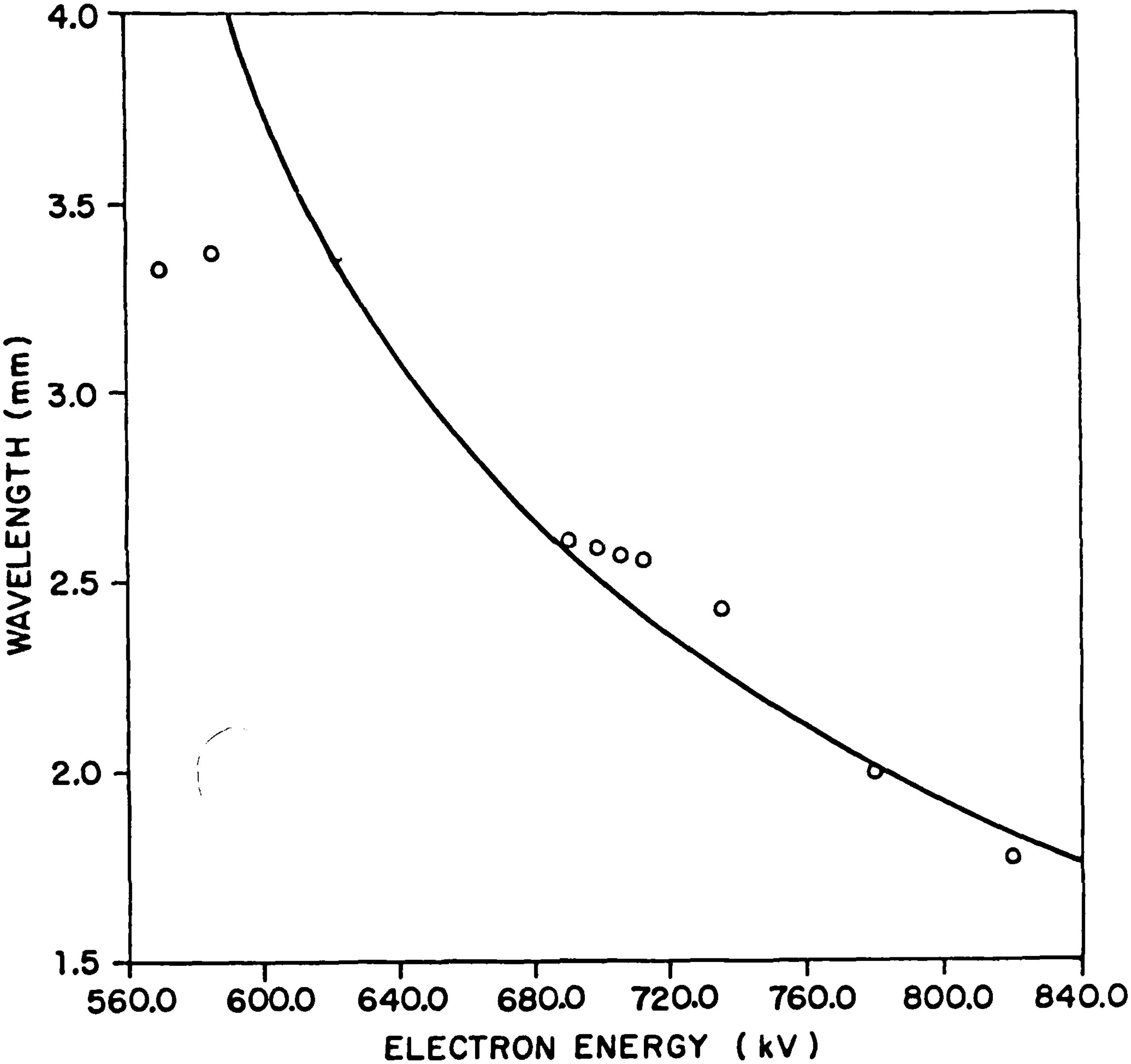
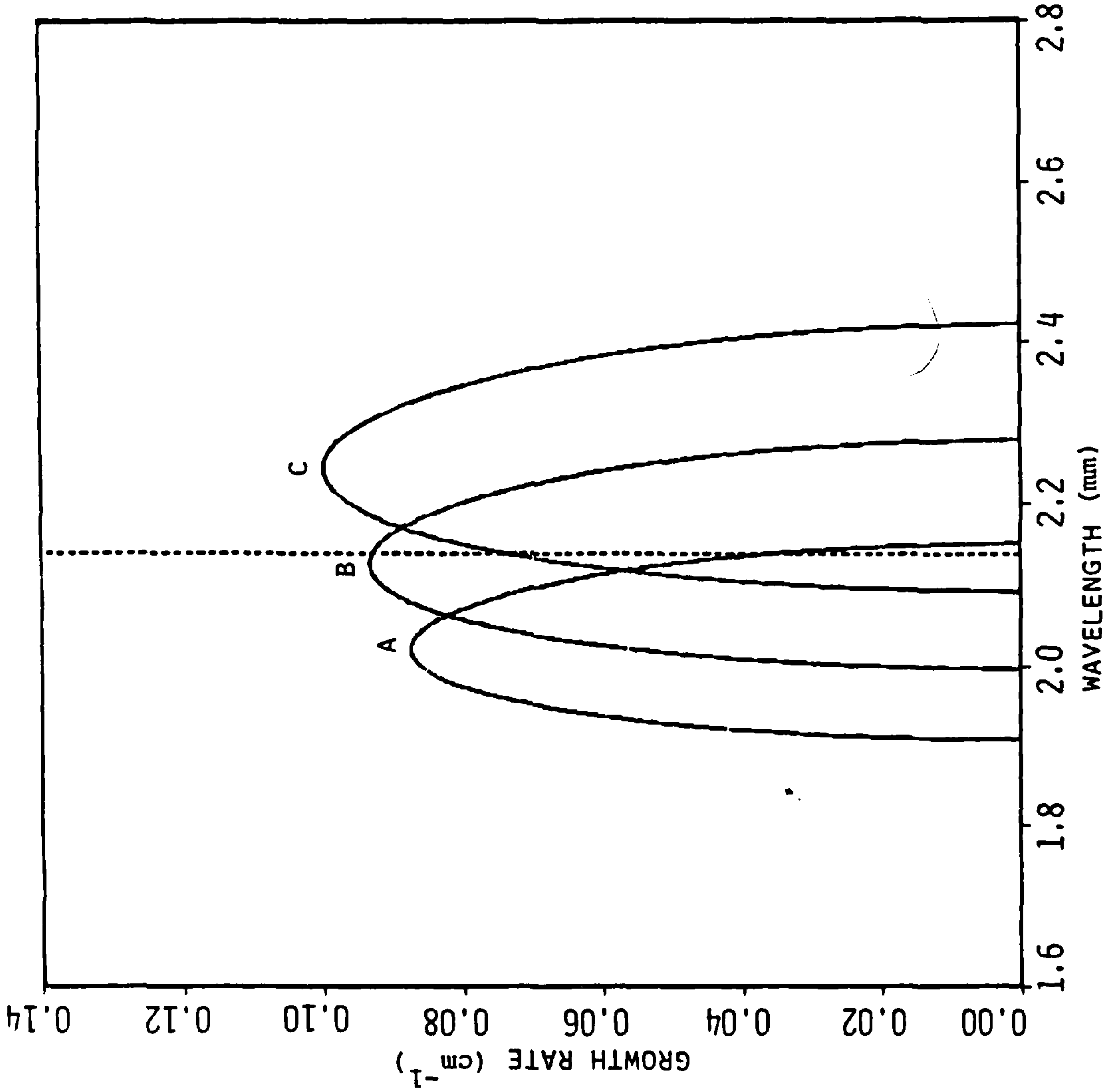

4.0
3.5
3.0
2.5
2.0
1.5
WAVELENGTH (mm)
560.0
600.0
640.0
680.0
720.0
760.0
800.0
840.0
ELECTRON ENERGY (kV)

FIGURE 4



A
B
C
GROWTH RATE (cm^{-1})
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
WAVELENGTH (mm)
1.6
1.8
2.0
2.2
2.4
2.6
2.8

FIGURE 5

B: Design of an Efficiency-Enhanced Raman FEL Oscillator

(F.G. Yee and T.C. Marshall)

INTRODUCTION

Theoretical studies indicate(1) that the efficiency of a Raman free electron laser ("FEL") can be enhanced by properly "tapering" the undulator amplitude and/or period; under optimized conditions, efficiency of order 25% or more can be obtained. Already, a series of experiments at LANL and Boeing/Math Sciences (1) have shown that the efficiency of a Compton FEL may be improved roughly a factor of ten using these techniques.. However, very little consideration has been devoted to proving this concept in the case of Raman, or space charge dominated, FELs, particularly in the oscillator configuration. Using pulse line technology, with an 800kV, 200A beam, we shall show that a Raman FEL should produce roughly 25MW at a wavelength $\approx$ 2mm. Since the level of radiation inside the resonator is substantially higher, this opens the possibility of studying a "two-stage" FEL in the collective regime, where the millimeter radiation is backscattered from the cold portion of the electron beam upstream from the undulator, regenerates inside the resonator, and appears in the lab at wavelength $\lambda_s \approx \ell_o/8\gamma_{\shortparallel}^4 \approx 0.1$mm. In what follows, we discuss the numerical solution (2) of the tapered undulator problem in one-dimension, appropriate to the design of the "first stage" high power oscillator(3). The results show that the efficiency of a Raman FEL oscillator can be improved roughly a factor of two using a variable-period undulator, even in a very short ($\approx$70cm) system using a short-pulse electron accelerator ($\approx$100nsec).

As an actual experiment is planned, we begin by summarizing the constraints under which it must be operated. For the electron beam, the electron $\gamma \approx 2.5$, with current density $\approx$ 1kA/cm^2. We have demonstrated in previous experimentation, using this beam, that the electron momentum spread is $\approx$ 0.6% in the absence of the undulator(4), and that substantial [10-20db] gain may be obtained at $\approx$1mm (5). As the high current density beam requires a guiding magnetic field, the space available for the undulator is only $\approx$ 70cm, and the quiver velocity induced on the beam by the electrons should be in the range $\leq$ 0.1-0.15c so that the momentum-spread induced by the undulator remains small (4). The pulse length of the accelerator is 150nsec, so this defines the time span over which the oscillation must build up from noise, saturate, and interact with the "tapered" undulator. We shall choose an undulator period ℓ_0 =1.7cm, which will stimulate radiation at a wavelength $\ell_0/2\gamma_\parallel^2 \approx$ 1.8mm. The configuration of the planned laser is shown in Fig 3, to be discussed in section IV.

After giving appreciable energy to the laser signal field, the electrons in an FEL are slowed down and fall out of resonance with the ponderomotive potential well. Among the possible efficiency enhancement schemes, two are studied: [1] slowing the well by decreasing the period of the undulator magnet , so the phase velocity is decreased to synchronize with the electrons; [2] compensating for the loss of parallel (axial) energy by decreasing the amount of pumping, that is , decreasing the undulator field amplitude along the beam direction. The latter decreases the path length travelled by an electron so as to maintain the resonance frequency constant

along the system. These methods may be combined.

In the design, one strives initially for adequate small signal gain, say >10db per pass, so that the spontaneous radiation will grow from noise in a few passes through the Fabry-Perot resonator, and that the growth on each pass will substantially exceed the mirror and diffraction losses (at millimeter wavelength, these could be as high as 90%). If the net power gain is G, and there are M passes, the output will grow to

$$P(M)/P(0) \approx M\, r\, e^{GM} \tag{1}$$

The magnitude of the signal vector potential at saturation (end of the small signal regime) is

$$A_{sat} \approx \frac{\gamma}{2}\sqrt{\gamma_{\parallel}^{5}\left(\omega_p/k_0 c\right)^3}\cdot\left(mc^2/e\right) \tag{2}$$

which is $\approx$ 10CGS volts. We find typically that about 35cm of the undulator is enough to provide a growth to saturation in perhaps eight bounces of the radiation, providing the undulator amplitude is high [roughly 2kG in the absence of a guiding field, so that the electron quiver velocity is at least 10%c]. In the regime of small signal growth, the tapered region is not effective. Enhancement of efficiency is dependent on large-signal gain in the tapered end region of the undulator in the last pass or two of the radiation. The design of this region provides a trade-off between the small signal gain and the large signal efficiency enhancement.

It is important to understand that in the oscillator one

cannot assume that the intial signal is known at the undulator entry. Thus one endeavors to optimize the oscillator performance in such a way that it remains satisfactory over a wide range of initial signal amplitudes. The theory requires a value of signal specified at the input, and it calculates the growth in a single passage along the undulator. If the initial signal is sufficiently small, the signal grows exponentially at the resonance wavelength; large signals involve trapping of electrons in potential troughs and exhibit saturation and periodic variation of amplitude.

THEORY

The design is based on a one-dimensional numerical model of the generalized pendulum equation (2):

$$d^2\psi/dz^2 = -\left(\frac{e}{\gamma mc^2}\right)2k_s K_0 A_w A_s \sin\psi + \frac{2\omega_p^2}{\gamma c^2\gamma_\parallel^2}\left[\langle\cos\psi\rangle\sin\psi - \langle\sin\psi\rangle\cos\psi\right] + \frac{dk_s}{dz} - \frac{1}{4}\left(\frac{e}{\gamma mc^2}\right)^2\frac{\omega_s}{c}\frac{d}{dz}A_w^2 + \frac{dK_0}{dz} \tag{3}$$

where ψ is the phase and ω_p is the plasma frequency, together with the self-consistent signal wave equations, approximated in the limit of slowly-growing amplitude on the scale of the wavelength:

$$\left.\begin{aligned}(\omega_s/c - K)A_s(z) &= \frac{\omega_p^2}{2c^2}\frac{V_\parallel}{\omega_s}\left[A_w\left\langle\frac{\cos\psi}{\gamma}\right\rangle\right]\\ \sqrt{K}\,\frac{d}{dz}\left(A_s\sqrt{K}\right) &= \frac{\omega_p^2}{2c^2}\frac{V_\parallel}{c}\left[A_w\left\langle\frac{\sin\psi}{\gamma}\right\rangle\right]\end{aligned}\right\}, \tag{4}$$

A_s, A_w = vector potential of signal wave and undulator;
$k_0 = 2\pi/\ell_0$, $k = (d\phi/dz + \omega_s/c)$, ϕ = optical phase, $K_s = 2\pi/\lambda_s$.

The first term on the left of eq (3) is the conventional pendulum term, while the second accounts for the effects of high space-charge density. The latter must be included when the density of electrons exceeds

$$n > K_0^2\gamma^3 A_w A_s/4\pi mc^2 = \frac{B_\perp E_s\gamma}{8\pi mc^2} \tag{5}$$

The third and fourth terms account for the change of optical phase (ϕ) and the undulator amplitude variation, while the last involves the change of undulator period. As initial conditions, we choose ℓ_0, γ, K_s, the system parameters. A finite

number of electrons (i= 1,2,......n) with initial phases $\Psi_i(0)$, are evenly distributed between $-\pi$ and $+\pi$, to simulate the random phase of the electron ensemble without any special injection preparation; in addition, these electrons will also have different energies within a range $(\delta\gamma/\gamma)_{\parallel}$, in order to simulate the typical beam momentum spread to be expected ($\approx$ 1%). Parameters to be optimized are A_w, L (length of untapered section), $\lambda_0(z)$ (the period), $A_s(0)$ (the initial signal amplitude), and $\frac{\Delta\omega}{\omega}$, the frequency mismatch at injection. To prescribe in a proper way, the electron energy must be known at every position by solving (2)

$$\frac{d\gamma}{dz} = -2\gamma K_0\left(\frac{e}{mc^2}\right)A_w A_s \sin\Psi - \frac{eE_z}{mc^2} . \qquad (6)$$

In solving for the electron energy using eq (6), the interaction with the space charge field may be neglected, as the electrostatic energy in the space charge fluctuations is smaller (6) than the energy of the electromagnetic wave by a factor $\gtrsim$ 10. In the small signal limit, eq (3) reduces to the small signal Raman or Compton gain result. We assume the electron beam is nearly cold, that is, the axial momentum of all electrons is nearly the same, which is satisfactory providing the momentum spread is negligible compared with the ponderomotive amplitude:

$$\left(\delta\gamma/\gamma\right)_{\parallel} \leq \frac{e}{mc^2}\sqrt{A_w A_s} , \qquad (7)$$

in which event the electrons can easily be trapped in the "buckets" of the ponderomotive wave potential.

In optimizing the undulator period profile, we use a "resonant electron approximation":

$$\frac{d\gamma_r}{dz} = \frac{-k_s(z)A_s(z)A_w \sin\psi_r}{\gamma_r} \cdot \left(\frac{e}{mc^2}\right)^2 \qquad (8)$$

and

$$\frac{d\psi_r}{dz} = 0 = k_0(z) - \frac{k_s}{(1+\beta_\parallel)\gamma_\parallel^2\beta_\parallel}\left\{1 + \left(\frac{eA_w}{mc^2}\right)^2 - 2\left(\frac{e}{mc^2}\right)^2 A_w A_s(z)\cos\psi_r + \left(\frac{e}{mc^2}\right)^2 A_s^2(z)\right\} \qquad (9)$$

Equations (8) and (9), which neglect space charge, are useful in choosing a first approximation to the optimum $k_0(z)$. The actual calculation, however, uses eqs (3,4,6).

Results of the Calculation

The following parameters were chosen: pumping magnetic field = 2.0KG (see next section for the discussion pertaining to the guiding field effect which is the actual situation experimentally); $(\delta\gamma/\gamma)_{\parallel}$ = 1%; optimized resonant phase ψ_r = 10degrees; $\gamma(0)$ = 2.425. The undulator is helical and drives a right-handed circularly polarized electromagnetic wave.

Figure 1 shows the result for the case of an undulator having constant amplitude and period; (1a) is the growth of a small amplitude test signal along the undulator. Fig 1b shows what happens when the initial signal is large (in this example, 4.0statvolt): synchrotron oscillations are apparent. If the beam were cold, the synchrotron oscillation would be even more pronounced. As the input "large" signal to the oscillator is not known-- it depends on growth during several radiation bounces in the small signal regime, and therefore depends on unspecific initial conditions-- we might anticipate that on the average the output efficiency of the oscillator might be roughly 8%.

For the tapered undulator example, we have found that a suitable choice consists of a leading uniform period section, 20cm long (which produces adequate small signal gain), followed by a 30cm tapered period section (which promotes enhanced efficiency). Fig 2a shows the period profile (above), and the small signal power gain in this section is about 26db. Fig2b shows the efficiency for three different values of "large" signal: 1.0, 2.0, and 4.0statvolts at the input of the

oscillator. After one pass, the typical output signal shows an efficiency which is of order 15%, that is, roughly a factor of two enhancement over the untapered period simulation. Thus, in an actual experimental situation, a modest tapering of the undulator period should cause a marked improvement in the power obtained from the oscillator. Furthermore, at the end of the undulator the power extracted is not particularly sensitive to the signal level present at the input on the last pass; for this reason we believe that our calculation should satisfactorily model operation as an oscillator.

The calculations have been done in one-dimension, taking unity filling factor. We have found that better results were obtained by changing the undulator period rather than the amplitude.

Experimental Configuration

The electron beam will be cylindrical, with diameter about 5mm, and is obtained from an aperture in a field emission diode; a similar beam in the same drift tube [dia = 1.9cm] was found to have an intrinsic parallel momentum spread of 0.5% from the combined effects of emittance and space charge(4). The undulator will be a bifilar helix, machined with a variable pitch by a numerically-controlled lathe. A transverse magnetic field on-axis $\approx$ 600G is readily produced by a capacitor-bank discharge through the winding. Although the numerical work did not include a guiding magnetic field, this is necessary to contain the space charge forces of the beam in an equilibrium. If we require that the quiver velocity in the experimental

situation be the same as that found necessary in the simulation, the guiding field (B_0) permits one to operate the laser with smaller pump magnetic field amplitude. A large quiver velocity is obtained as the undulator is operated near "magnetoresonance", viz $eB_0/\gamma K_0 mc^2\beta_{\parallel}$ = 0.7; this is given by

$$v_{\perp}/v_{\parallel} = \frac{eB_{\perp}/mc}{(eB_0/mc - \gamma K_0 v_{\parallel})} \quad (10)$$

where $B_{\perp}$ is the undulator field. It is expected that stable "type I" orbits (7) will result in this undulator. As the period of the undulator is decreased, the quiver velocity will be reduced from two effects: (1) Moving farther from magnetoresonance, and (2) reduction of $B_{\perp}$ owing to the increasing ratio of the coil winding radius to the period. All these effects combine to reinforce the original taper, that is, they combine to maintain the resonant energy. However, in the simulation, only the period is allowed to change. Therefore, the actual change in undulator period required is less than that introduced into the theoretical model.

Power will be recirculated in a multimode resonator between two mirrors (Fig 3 shows the laser configuration anticipated). The end mirror, having a coupling hole, is to be fitted into a larger pipe; thus off-axis resonant modes will suffer high diffraction and will not be regenerated. At the upstream end of the system, we use a dielectric mirror, fitted onto a wedge having low dielectric factor. An appreciable fraction of the radiation will be reflected from the high dielectric constant interface [K ~ 15], and this may be

reinforced still more by choosing the thickness of the mirror slab to be half-wavelength. The advantage of this scheme is that the dielectric mirror does not perturb the radial electrostatic geometry of the beam and the drift tube: then the electron beam momentum spread will remain adequately low, as in the original design.

Fig. (2a) shows that the small signal, single-pass power gain is $\gtrsim$ 500 ($\gtrsim$1db/cm). Assuming 90% power loss in the feedback system (i.e. $P_{out}/P_{in} = 50$), and that noise power $\lesssim$ 1w is present at the input, then from $P(M)/P(0) = 10^8$ and eq 1 , we find 5 optical bounces (30nsec) are required to reach saturation. This is far less than the accelerator pulse length (150nsec).

Spectral measurements, particularly bandwidth, will be made initially with a Fabry Perot external interferometer. We expect the FEL system to exhibit a primarily homogeneously-broadened line, and therefore appreciable line narrowing should result [unlike the original (8) Raman FEL, where the gain was influenced by inhomogeneous broadening effects]. Power measurement will be made using a calorimeter cone fabricated of "Macor", a machineable glass with high absorption at millimeter wavelength. Operation of the actual laser should be possible in 1986.

ACKNOWLEDGMENT This research was supported by the ONR, grant N 00014-79C-07969

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FIGURES

Fig. 1: Signal growth and saturation in a Raman FEL having an undulator (or "wiggler") with constant helical pitch. (a): Small signal growth, constant undulator period above; (b): saturation and synchrotron oscillations at high signal power.

Fig. 2: Signal growth and saturation in a Raman FEL having an undulator with programed pitch (1.7cm for the first 20cm, linear taper to 1.4cm over the remaining 50cm; same electron beam conditions). (a): Small signal growth, variable undulator pitch above; (b) saturation and synchrotron oscillations at large signal power (the different curves show the effect of variation of the large signal amplitude).

Fig. 3: Proposed experimental configuration. The mirror on the upstream side is a high dielectric constant disk mounted on a low dielectric constant wedge.

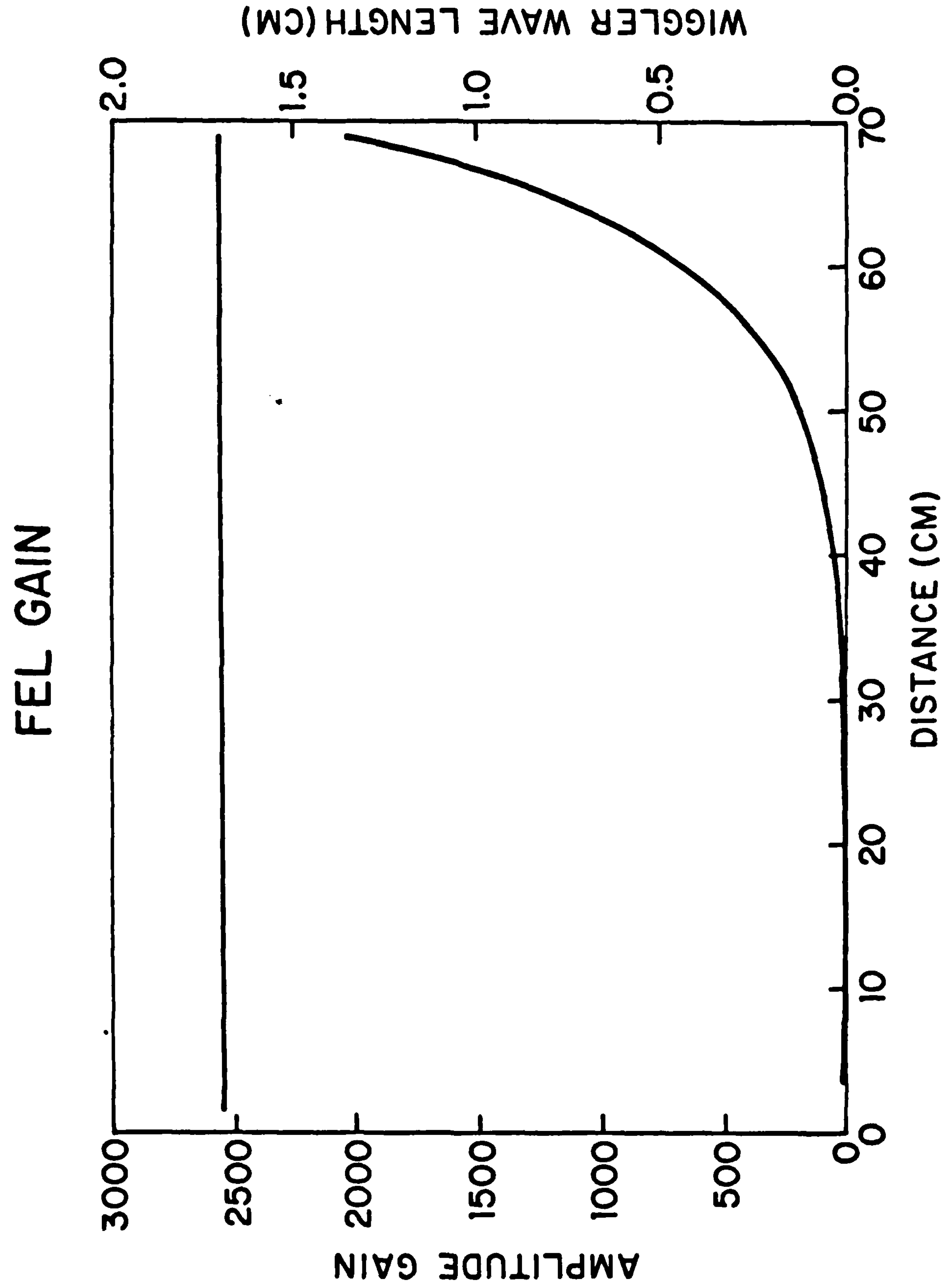
FEL GAIN
WIGGLER WAVE LENGTH (CM)
2.0
1.5
1.0
0.5
0.0
AMPLITUDE GAIN
3000
2500
2000
1500
1000
500
0
DISTANCE (CM)
0
10
20
30
40
50
60
70

FIGURE 1a

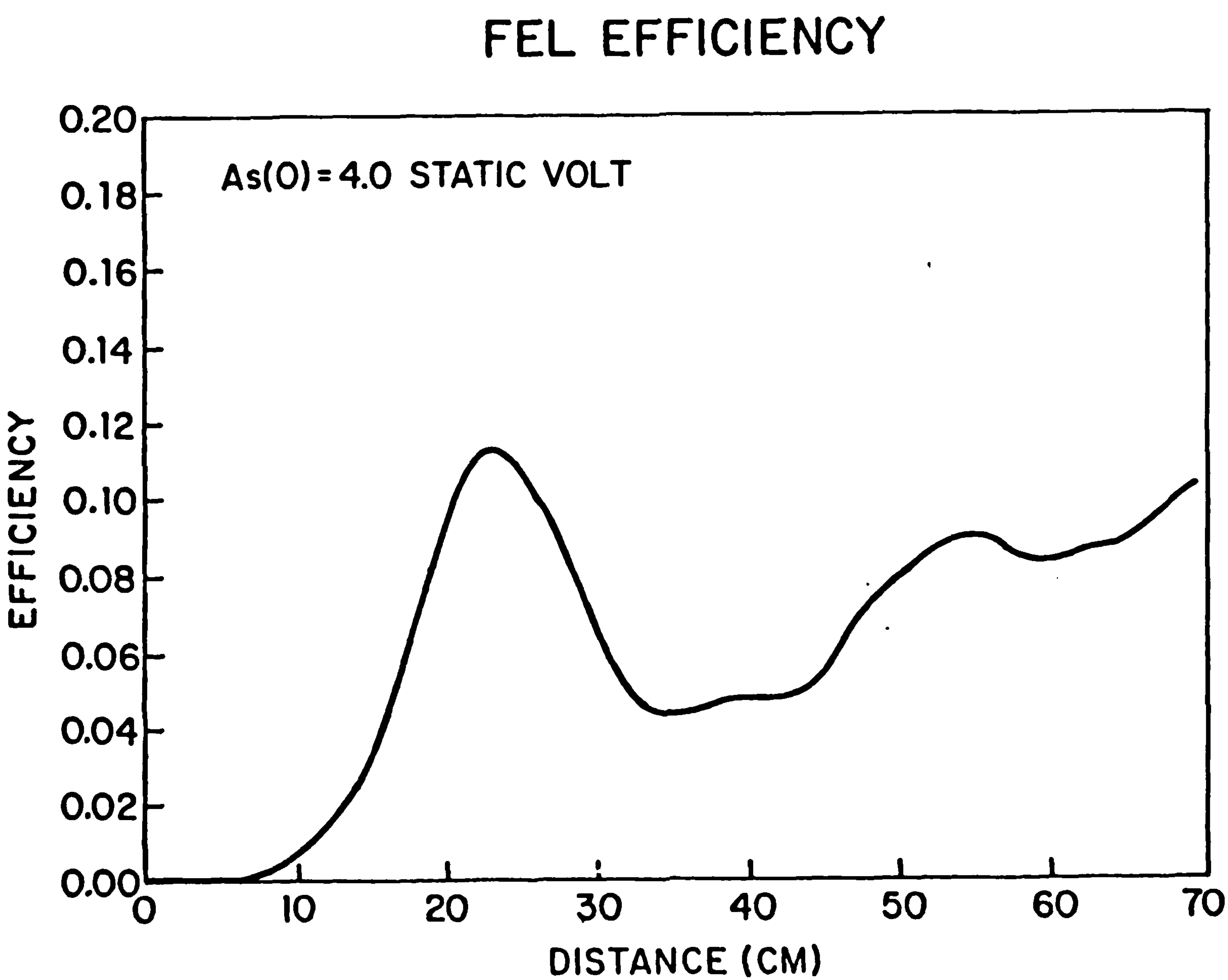
FEL EFFICIENCY
As(O)=4.0 STATIC VOLT
EFFICIENCY
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
10
20
30
40
50
60
70
DISTANCE (CM)

FIGURE 1b

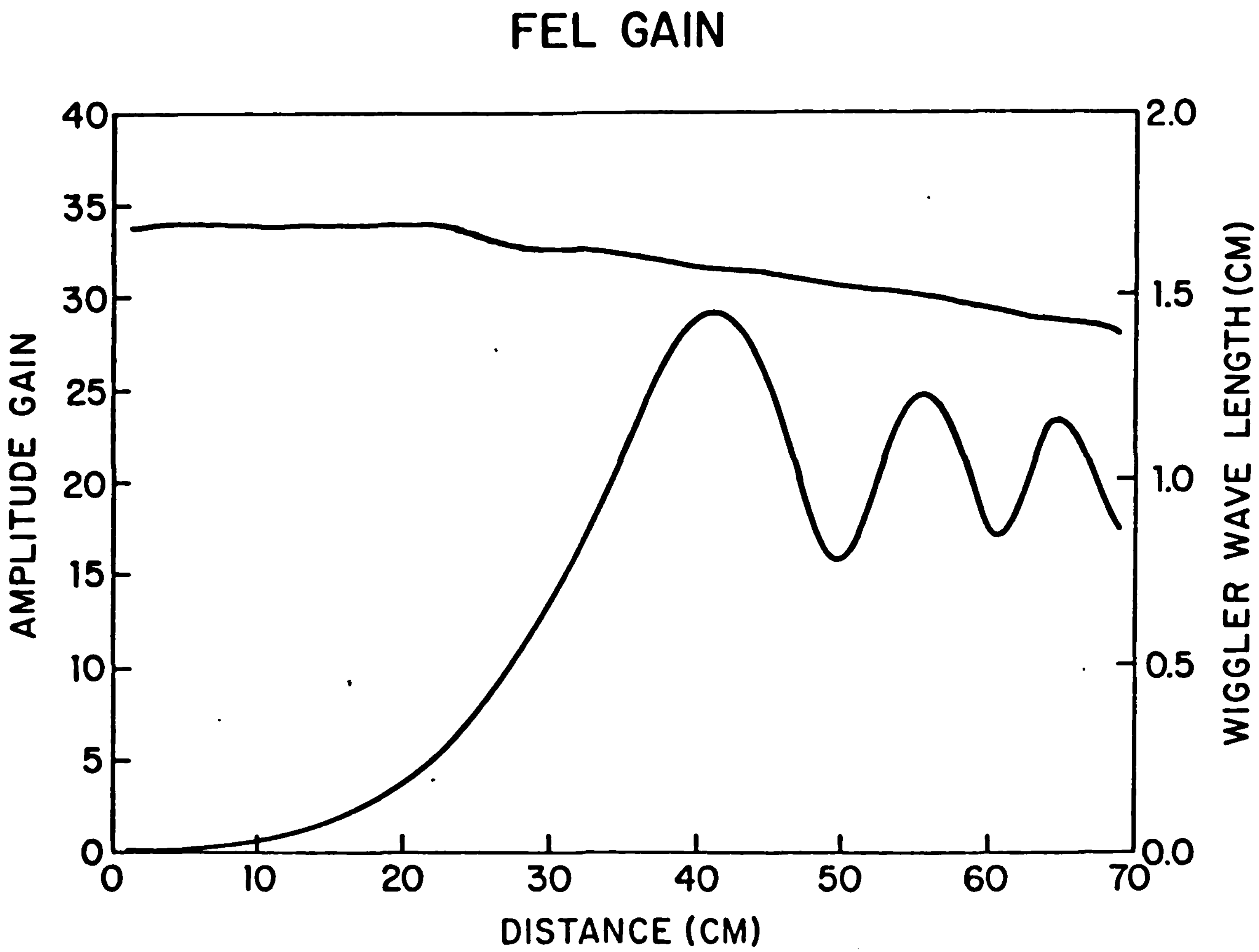
FEL GAIN
AMPLITUDE GAIN
0
5
10
15
20
25
30
35
40
WIGGLER WAVE LENGTH (CM)
0.0
0.5
1.0
1.5
2.0
DISTANCE (CM)
0
10
20
30
40
50
60
70

FIGURE 2a

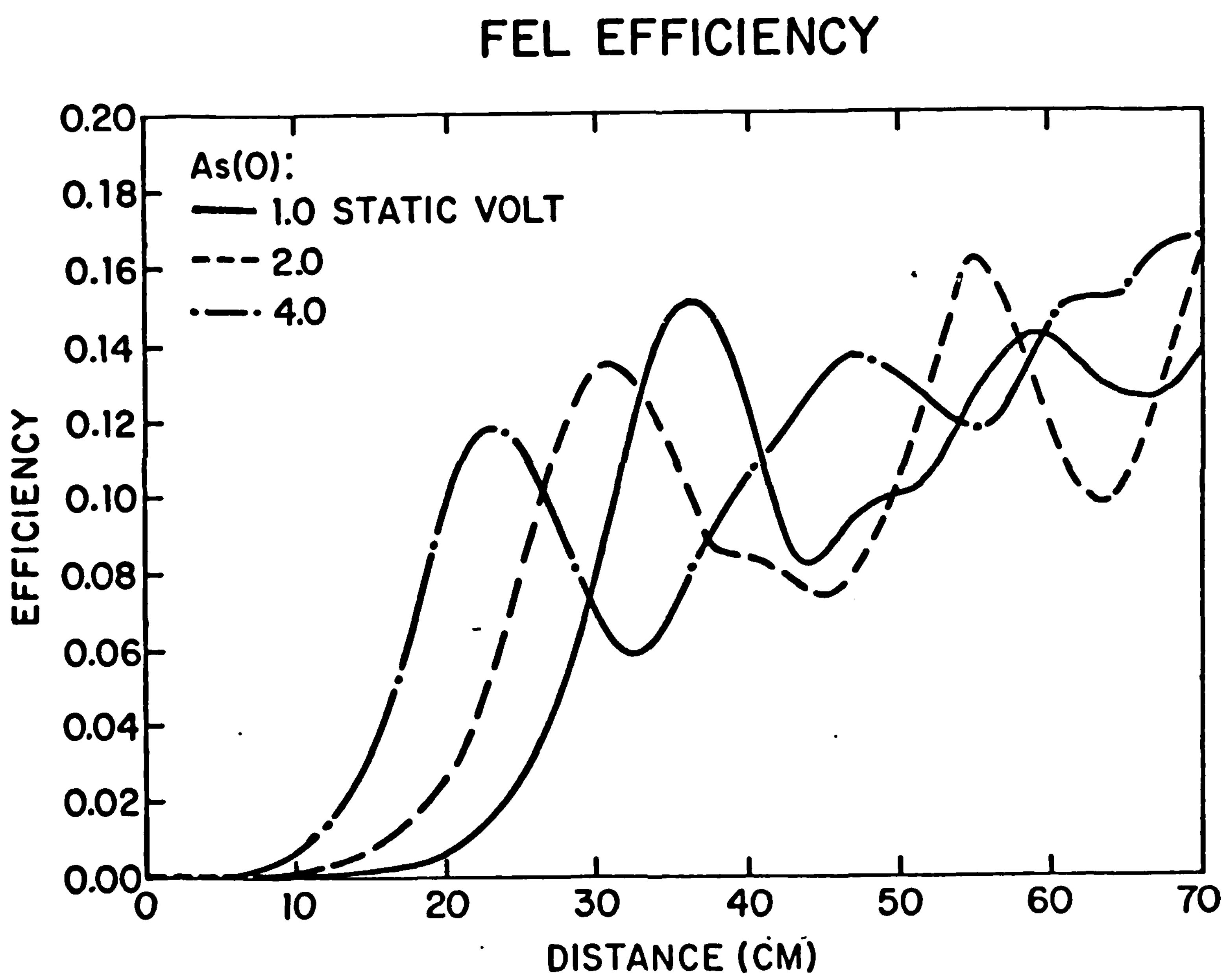
FEL EFFICIENCY
As(O):
1.0 STATIC VOLT
2.0
4.0
EFFICIENCY
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
10
20
30
40
50
60
70
DISTANCE (CM)

FIGURE 2b

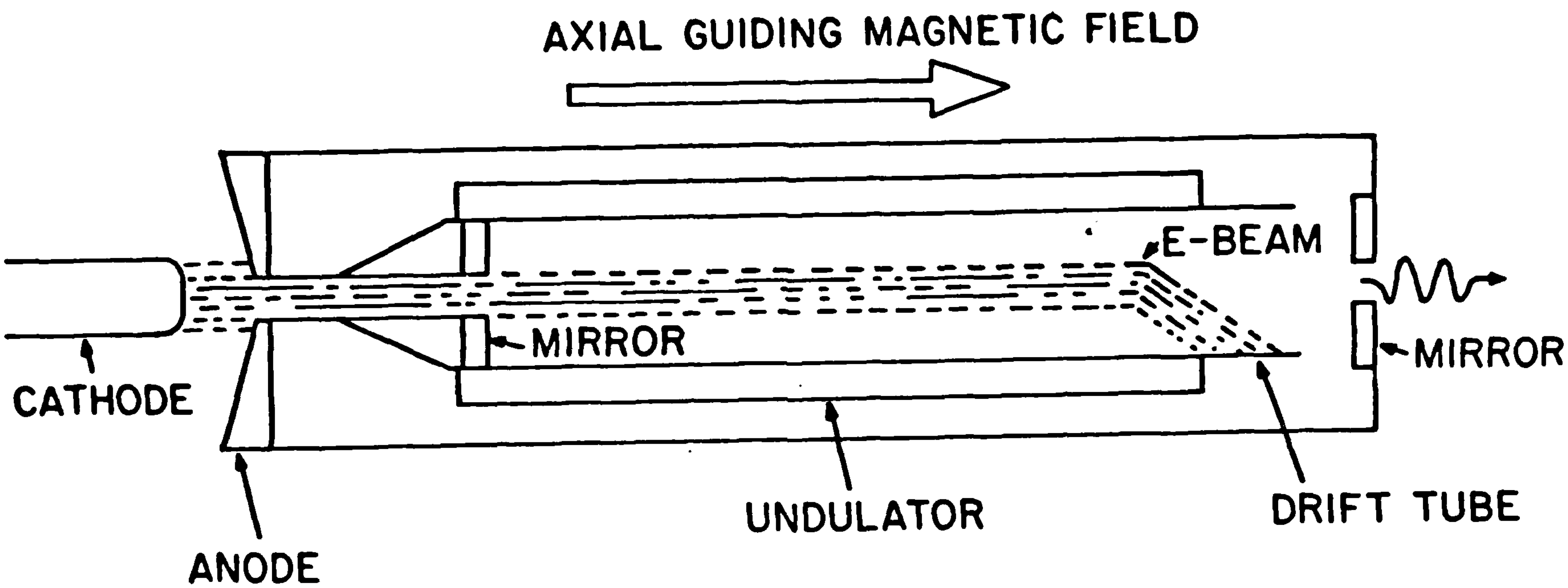
AXIAL GUIDING MAGNETIC FIELD
E-BEAM
MIRROR
MIRROR
CATHODE
ANODE
UNDULATOR
DRIFT TUBE

FIGURE 3

III. PUBLICATIONS AND PRESENTATIONS

- "Design of an Efficiency-Enhanced Raman FEL-Oscillator," F.G. Yee and T.C. Marshall, IEEE Trans. Plasma Science (accepted for publication)

- "Parallel Velocity Spread Induced in a Relativistic Electron Beam by an Undulator," S.C. Chen and T.C. Marshall, IEEE Journ. Quantum Electronics, QE-21, 924, 1985

- T.C. Marshall, RAMAN FEL EXPERIMENTS, Chapter 13 of Free Electron Laser Handbook, Ed: Pellegrini, North Holland (accepted for publication)

- T.C. Marshall, Free Electron Lasers, Macmillan, New York Published, January 1985

- Presented at the November '84 APS/Plasma Meeting in Boston -

  "A Raman-FEL Amplifier Experiment at 1.22mm," J. Masud, T.C. Marshall and S.P. Schlesinger, BAPS 29, 1341 (1984)

  "A Tapered-Undulator Raman Oscillator," F.G. Yee and T.C. Marshall, BAPS 29, 1342 (1984)

- Presented at Center for Theoretical Physics, Trieste, Italy, Feb. 1985, T.C. Marshall, "The Raman Free Electron Laser"

- To be presented at the Seventh International Free Electron Laser Conference, Tahoe City, CA, Sept. 1985, T.C. Marshall, "Raman Free Electron Lasers," (paper to be published in Conference Proceedings: 'A Raman FEL at 2mm Wavelength,' J. Masud, F.G. Yee, T.C. Marshall and S.P. Schlesinger)

- To be presented at the '85 APS/DPP meeting in San Diego, "Gain Measurements in a Millimeter Wave Collective FEL Amplifier," J. Masud, F.G. Yee, T.C. Marshall and S.P. Schlesinger

- T.C. Marshall is a member of the APS study group on Directed Energy Weapons Technology Assessment

IV. Status Report:

Graduate Students:

J. Masud --- dissertation research in progress

F.G. Yee --- dissertation research in progress

Other Support for Principal Investigators:

T.C. Marshall --- also participating in US DOE grant DE-AC02-76ET53016, "High Beta Tokamak Studies"

Financial - current and projected:

Contract funds --- $178,934, 2/1/85 - 1/31/86

Expected surplus --- none

Permanent Equipment:

Purchased since Feb. 1, 1985

- 1 Mu2-6F Fixed Tuned Frequency Doubler
  fout = 159-161 GH_z
  5 MW output with BMU2 bias box

- 1 80 GH_z Gunn Source, Mechanically Tuned
  ± 700 MH_z,

- 1 Waveguide Taper TRG, model # V692G Flanged with UG387 (round) Flanges

END

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